

APPENDIX B. OVERVIEW OF B-ISDN

The ITU-T (formerly CCITT) began work on B-ISDN standards during its 1984-1988 study period. These standards outlined a system that would be a significant departure from any previous telecommunications system. The system would be built on a foundation that ITU-T dubbed the synchronous digital hierarchy (SDH) and the asynchronous transfer mode (ATM). The SDH and ATM standards defined an optical fiber-based network with channels operating at rates of multiples of 155.520 Mbit/s. U.S. standards bodies developed the synchronous optical network (SONET) standard, which is similar to the SDH system. Details of the SONET and SDH protocols are discussed in Section B.1.

The ITU-T continued to work on the development of B-ISDN Recommendations and, in 1991, adopted a protocol reference model for use in B-ISDN, Recommendation I.321. This protocol reference model is shown in Figure B-1. The protocol reference model is similar in concept to the OSI protocol stack, however, there are some differences. For example, the divisions between the layers of the B-ISDN model do not correspond exactly to the levels of functionality in the OSI model (e.g., some B-ISDN protocol layers are divided up into sub-layers). The sub-layers and their respective functionalities are shown in Table B-1. The ATM and AAL protocols are discussed in sections B.2 and B.3, respectively.

B.1 SONET/SDH Protocol

SONET and SDH were developed to provide high-speed reliable transport of digital signals. During the development process, work was conducted in both the U.S. national standards committees and the ITU. Table B-2 shows the data rates for a variety of SONET and SDH channels. SONET channels are referred to with the label STS¹ (for synchronous

¹SONET signals are also referred to with the label OC (for optical carrier). STS is generally used with electrical signals while OC is used with optical signals. For simplicity, STS has been used throughout this report.

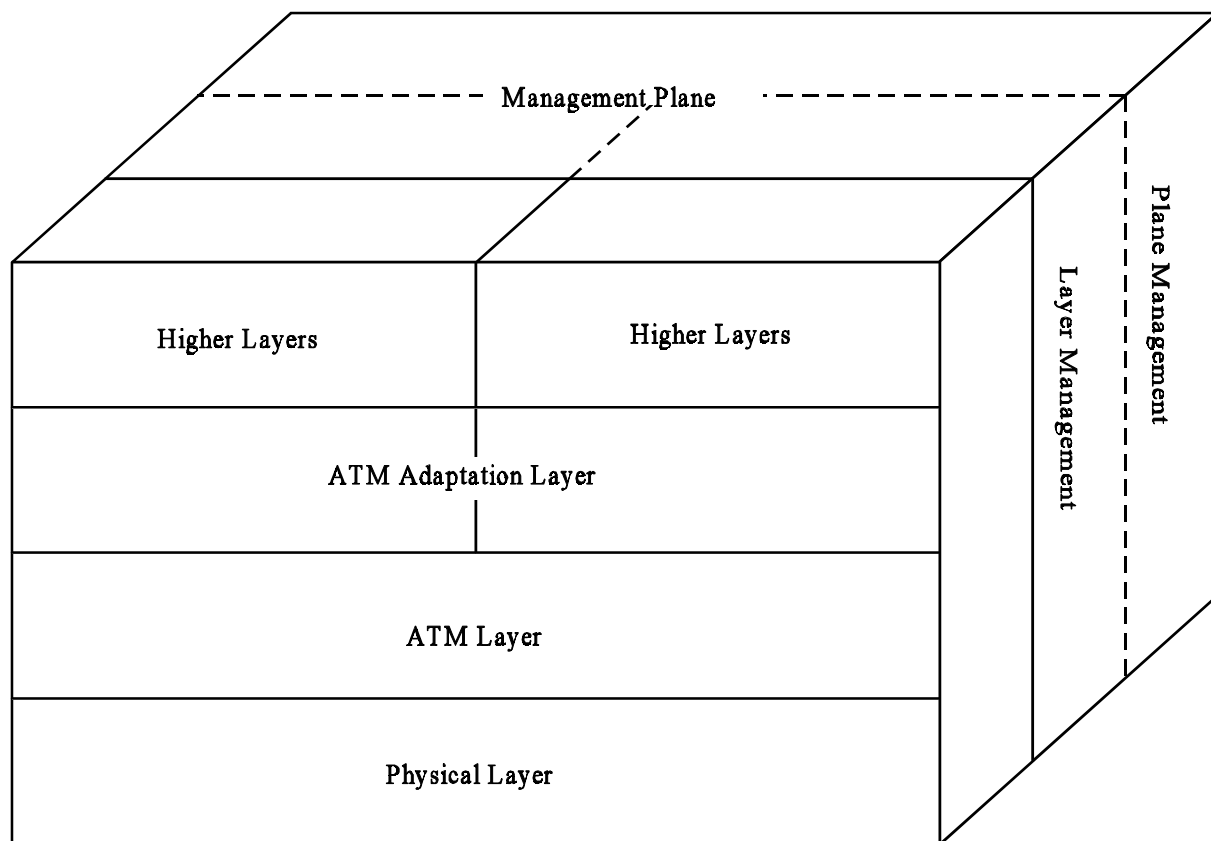


Figure B-1. B-ISDN protocol reference model.

transport signal) followed by the multiple of the 51.84 Mbit/s base rate that the channel carries (e.g, STS-3=51.84 Mbit/s•3=155.520 Mbit/s). SDH channels are referred to with the label STM followed by the multiple of the 155.520 Mbit/s base rate that the channel carries.

The SONET STS-1 stream is divided into 810-byte frames. This is generally depicted as a block of information consisting of nine rows of 90 bytes each. (Figure B-2a.) The first three bytes of each row (i.e., the first three columns of the frame) are transport overhead information. In addition to this fixed overhead, there is a floating overhead component that occupies one column of the payload field. This is path overhead. The transport overhead is used to differing degrees by every device in the network, while the path overhead is only used when the data in the frame is decoded.

Table B-1. Functions of the B-ISDN in Relation to the Protocol Reference Model*

	Function	Layer	
LM	Higher Layer Functions	Higher Layers	
	Convergence	CS	AAL
	Segmentation and reassembly	SAR	
	Generic flow control Cell header generation/extraction Cell VPI/VCI translation Cell multiplex and demultiplex	ATM	
	Cell rate decoupling HEC sequence generation/verification Cell delineation Transmission frame adaptation Transmission frame generation/recovery	TC	PL
	Bit timing Physical medium	PM	

*Key:

AAL	ATM Adaptation Layer	SAR	Segmentation and Reassembly Sublayer
ATM	Asynchronous Transfer Mode		
CS	Convergence Sublayer	TC	Transmission Convergence Sublayer
LM	Layer Management		
PL	Physical Layer	VCI	Virtual Channel Identifier
PM	Physical Medium Sublayer	VPI	Virtual Path Identifier

Table B-2. SDH and SONET Channel Rates

Channel Rate (Mbit/s)	SDH Level	SONET Level
51.840	<not used>	STS-1
155.520	STM-1	STS-3
622.080	STM-4	STS-12
1244.160	<not used>	STS-24
2488.320	STM-16	STS-48

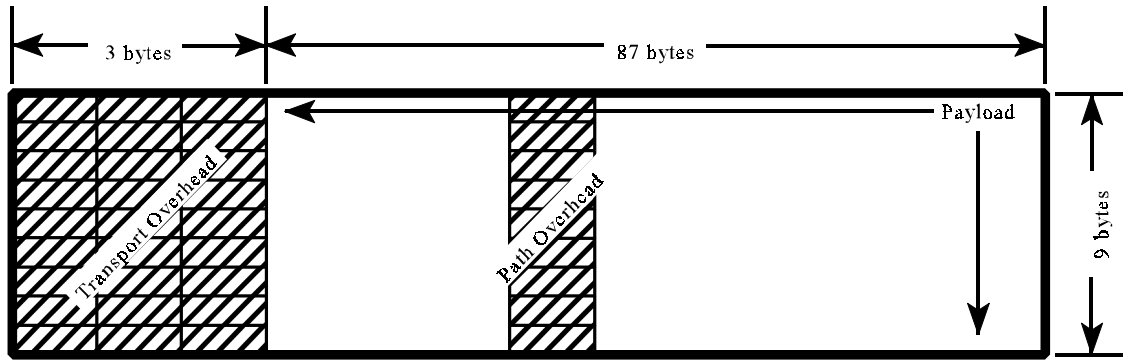
To form higher rate channels, these frames are multiplexed together using byte interleaving. A 155.52 Mbit/s STS-3 has three of these frames interleaved as shown in Figure B-2b. Note that all of the overhead information is included in the interleaving, as well. In the 2430 byte STS-3 frame, there is 108 bytes of overhead information. This is somewhat different from the overhead structure of an STM-1 frame of the same rate. In the 155.52 Mbit/s STM-1 frame, there is only one column of path overhead floating in the payload space as opposed to the three columns in an STS-3. The framing structure of STM-1 is shown in Figure B-2c.

Note that the number of bytes of overhead in STM-1 is 18 bytes less than that of STS-3. In order to alleviate this difference and improve the interworking between the international and national standards, the U.S. national committees adopted a process called concatenation. In concatenation, the payloads of the STS-1 streams are combined under one set of path overhead bytes. This essentially equalizes the overhead with that agreed upon in the international standards bodies. Channels that use a combined path overhead are denoted by using a 'c' with the channel label. For example, the STS equivalent of STM-1 is called STS-3c. By concatenating the payloads of the three STS-1s, the ability to demultiplex the channel from an STS-3c to three STS-1s is lost.

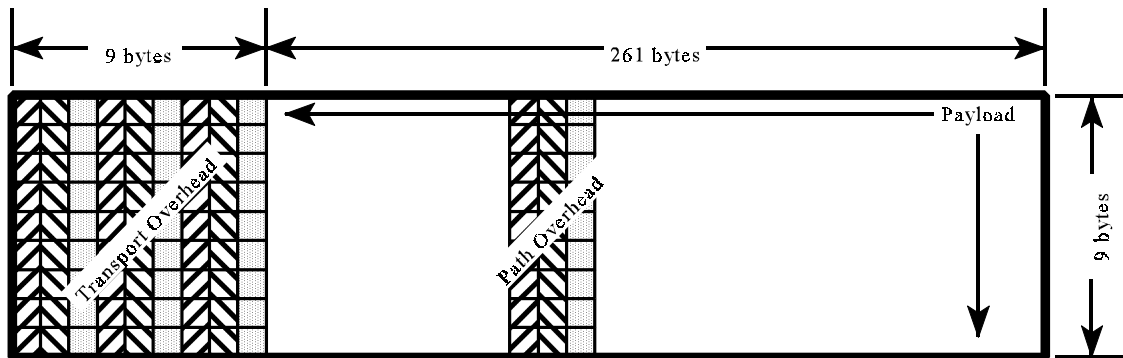
There remain some differences in nomenclature and usage of the overhead between STM-1 and STS-3c, but since the aggregate data rate and the amount of overhead are equal between the two systems, it is possible to achieve interworking between the U.S. standard protocols and the international standard protocols.

B.2 ATM Cell Structure

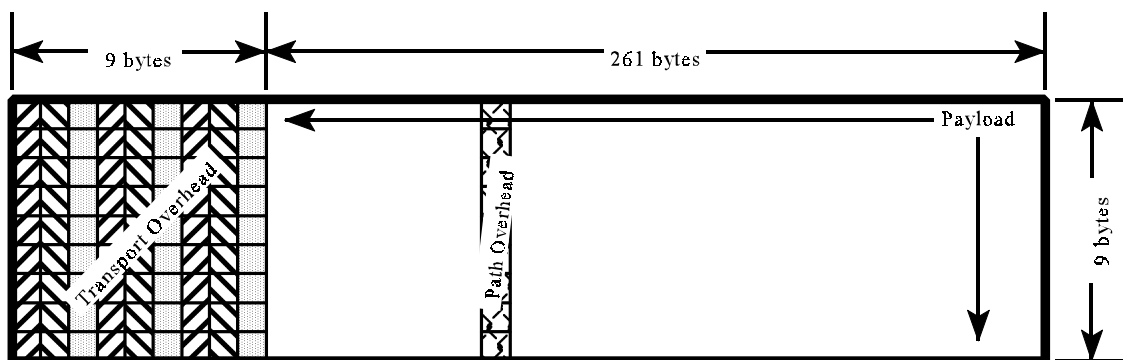
In B-ISDN, the SONET or SDH frames are used to transport smaller chunks of data as ATM cells. The ATM cells are asynchronous because they do not occupy a fixed space within the payload of the physical-layer frame. Within the physical-layer



a. STS-1 framing structure.



b. STS-3 framing structure.



c. STM-1/STS-3c framing structure.

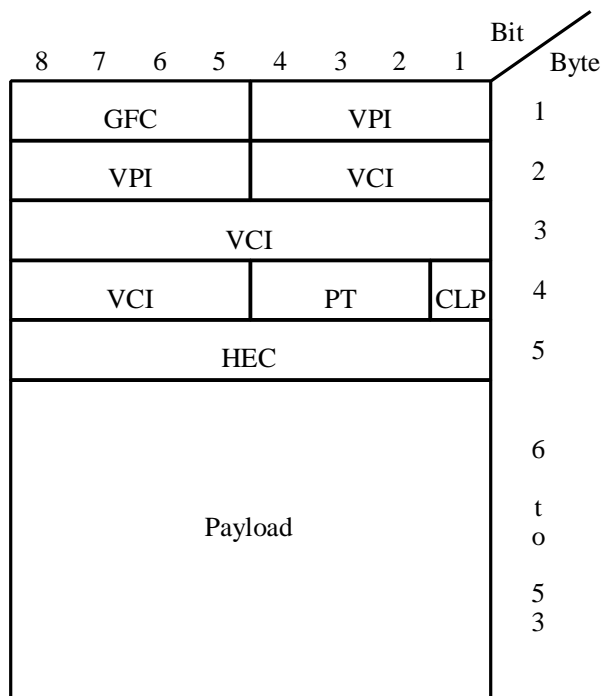
Figure B-2. Framing structure for SONET and SDH frames.

payload, ATM cells can start and end at any point, as long as all cells in the payload space are adjacent. ATM cells can even be split between two physical-layer frames, as long as the bytes of the ATM cell are contiguous amongst the two payloads.

An ATM cell is 53 bytes long. The first 5 bytes, the header, are overhead. The remaining 48 bytes are cell payload. There are two different formats for an ATM header. One for the user-network interface (UNI) and one for the interfaces between network nodes (NNI). The format of an ATM UNI cell is shown in Figure B-3. The only difference between a UNI and an NNI ATM cell is that the first 4 bits in an NNI cell are used for an enlarged virtual path identifier (VPI) rather than for generic flow control (GFC).

In the cell shown in Figure B-3, the VPI and VCI (virtual channel identifier) bits combine to form an “address” for the cell. This field helps ATM switches route the cell to the proper destination. The payload type bits indicate whether the cell contains user data, operations, administration and maintenance data; or resource management data. The cell loss priority (CLP) bit is used to indicate the cells that should be discarded first in the case of network congestion (i.e., when cells are entering queues to be transferred faster than the network elements can transmit them). If the bit is set to one, the cell should be discarded before discarding cells with a CLP of zero. The header error control field contains a cyclic redundancy check (CRC) that can detect multiple bit errors in the header, and correct a single bit error in the header. (See Section B.4 for more information on how the HEC is generated and used.) The uses of the GFC field are currently under study by the national and international standards bodies.

The ATM protocols provide few guarantees that a user’s data will arrive at its destination intact. In fact, the only integrity guarantee is that cells will exit the network in the order that they were inserted. Notably, ATM does not 1) request retransmission of lost or errored cells, 2) guarantee that all cells will be delivered or that all cells delivered belong to that



GFC Generic Flow Control
VPI Virtual Path Identifier
VCI Virtual Channel Identifier
PT Payload Type
CLP Cell Loss Priority
HEC Header Error Control

Figure B-3. ATM UNI cell structure.

destination, or 3) guarantee that cells inserted at a constant rate will be delivered at a constant rate.

Although this seems detrimental to the use of ATM, a significantly higher percentage of overhead would be required to implement these features; this would leave less room for user data. Thus, a compromise has been achieved with the current structure between throughput efficiency and accuracy of information transfer. It allows applications that require the high data rate achievable in B-ISDN networks to utilize that rate without the burdensome overhead that additional checks require. It also does not preclude application developers

from providing their own mechanism for these functions in the higher layer protocols. These developers will be assisted by information that provides a picture of how these ATM characteristics affect the performance of a given channel.

B.3 ATM Adaptation Layer

The ATM Adaptation Layer (AAL) segments blocks of user data for transmission by the ATM layer, and reassembles blocks of user data that have been received by the ATM layer. Because of the flexibility of the underlying ATM network, and the wide range of services that it is expected to carry, several AAL protocols have been adopted. In general, the use of an AAL protocol requires that a portion of the payload bytes of an ATM cell be given

up to additional overhead specific to a type of service. Some of the service aspects accounted for in the AALs are bit rate accounting methods, connection orientation, and transfer of timing. Currently, the service type definitions are in flux, and the reader is referred to the list of relevant recommendations provided at the end of this appendix..

B.4 Scrambling and HEC Functions

Many digital transmission systems use data scramblers to randomize the data patterns on the transmission links. Although these data scramblers are similar to those used for security encryption, the fundamental purpose of these scramblers is to prevent the transmission of undesirable data patterns, and not to secure data. For example, in many networks, repetitive data patterns can cause loss of synchronization or cause emission spectra that interfere with other signals in the network. For SONET/SDH networks, the scrambling function is used to prevent regular repetition of a sequence that could be mistaken for framing bytes.

The scrambling process uses the exclusive OR (XOR) operation with the current bit and specific bits in a feedback shift register. The descrambling process is similar, but uses a feed-forward shift register. An example scrambler and descrambler are shown in Figure B-4. In the figure, a represents the unscrambled bit stream, with a_n being the current bit; b represents the scrambled bit stream, with b_n being the current bit and b_{n-1} being the previous bit; and \oplus denotes the XOR operation. In the figure, $b_n = a_n \oplus b_{n-2} \oplus b_{n-5}$ and $a_n = b_n \oplus b_{n-2} \oplus b_{n-5}$.

For boundary conditions (i.e., for cases where n is less than the number of bits in the shift register), there are two possible scenarios. If both the scrambler and descrambler can be started synchronously, with a predetermined sequence in the shift registers, both elements will be instantly synchronized. If that is not possible, the descrambler will synchronize to

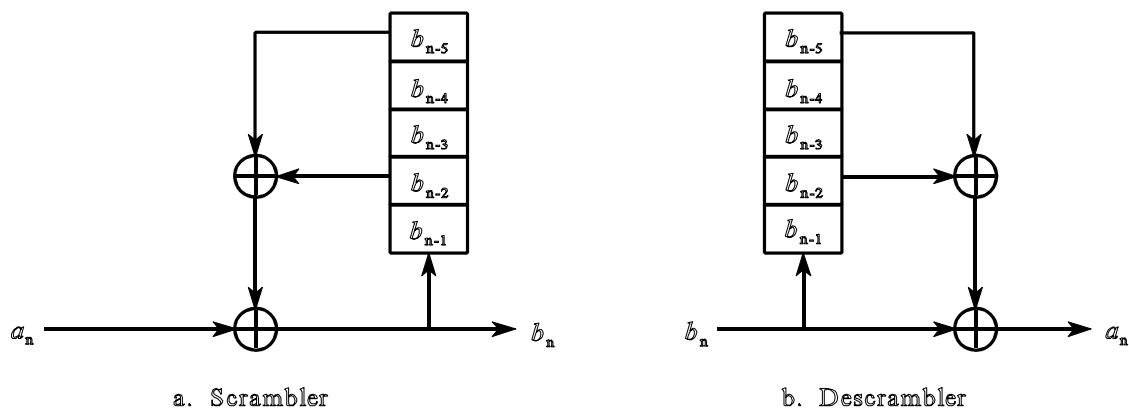


Figure B-4. Example scrambler and descrambler.

the scrambler as soon as enough bits have been received to fill the shift register. In the case of data being lost in transit, resynchronization will also take that number of bits.

Scrambling functions are usually referred to as polynomials. In the example shown in Figure B-4, the scrambling polynomial would be $1+x^{-2}+x^{-5}$, which means that the second and fifth preceding bits are XORed with the current bit. The scrambling polynomial for B-ISDN is $x^{43}+1$. The sign on the exponent is different, but the effect is to scramble/descramble by XORing the current bit with the bit that was sent/received 43 bits earlier. The ITU does provide a caveat to this, however, by stating that during transmission of overhead bytes, the scrambler is to be suspended but retain its state. Therefore, the scrambling bit is not always the 43rd previous bit in the physical-layer stream, but in the stream of ATM cell payload bits.

The scrambling function can also be represented by a bit sequence that is used to perform modulo 2 operations on the bit stream being transmitted: division for scrambling and multiplication for descrambling. The bit string representing the scrambler shown in Figure B-4 is 101001. An example of scrambling and descrambling a bit stream by this process is shown in Figure D-2. Note that the modulo 2 addition and subtraction process are

Error multiplication is the one negative effect to using a scrambling function. When a bit error occurs in the scrambled stream, that particular bit remain errored after the descrambling process. In addition, as that errored bit passes through the descrambler shift register, every time it is used to descramble another bit, another error will occur in the output data stream. For B-ISDN, each incoming bit is used twice, once to descramble itself and once to descramble the bit that arrives 43 bits later. Therefore, a single physical-layer bit error will actually cause two errors in the data delivered to the higher layer protocols.

Another use for this type of mathematics is the generation of cyclic redundancy checks (CRCs). The header error control (HEC) byte of an ATM cell is a CRC and it has three uses: 1) multiple bit error detection, 2) single bit error correction, and 3) cell delineation.

To generate a CRC, a finite length bit string (e.g., the header of an ATM cell) is divided by another bit string (generally represented by a polynomial). The remainder of this division becomes the CRC. The generation of the ATM HEC sequence begins by multiplying the first four bytes of the header by x^8 (i.e., eight trailing zeros are added to the first 32 bits). That 40-bit string is then divided by the polynomial $x^8 + x^2 + x + 1$ (i.e., the bit string 100000111). The remainder of that division (8 bits or less under the rules of modulo 2 mathematics) is XORed with the sequence 01010101 and placed in the HEC byte of the ATM cell header.

When an ATM cell is received, the division process is repeated and checked against the HEC value. If the results do not agree, the receiver determines if there was a single or multiple bit error. If the header contains a single bit error, the receiver attempts to correct the error. The exact algorithm for this is not specified in Recommendation I.432 but one simple algorithm would be to flip individual bits of the header in turn, testing the HEC for each one. If a single bit flip is found that resolves the HEC then that is the errored bit and can be corrected.

When more than a certain number of consecutive headers (α) contain errors (ITU Recommendation I.432 suggests $\alpha=7$), the receiver determines that it has lost synchronization, and enters a state where it searches for a valid ATM cell header. It chooses a 40-bit sequence to act as a proposed header and tests the validity of the HEC. If it is not valid, it shifts by one bit, and starts this process again.

If the HEC is valid, the receiver enters a pre-sync state and shifts by the length of a cell (53 bytes) to determine if there is a valid header located at the next appropriate place in the bit stream. When a sufficient number of appropriately placed, valid headers (δ) have been identified (ITU Recommendation I.432 suggests $\delta=6$), the receiver returns to the synchronized state. A state diagram depicting this process is shown in Figure B-3.

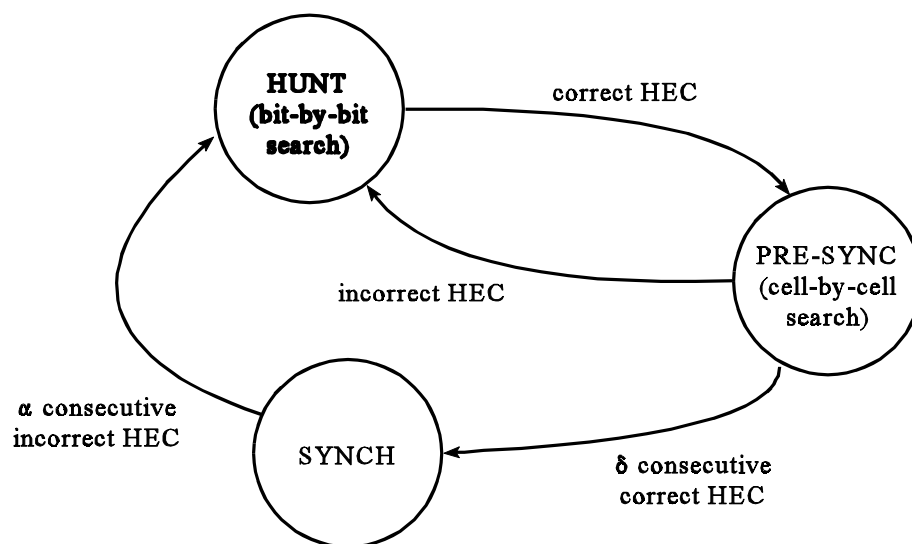


Figure B-3. Cell delineation state diagram.

B.5 Bibliography

J. Bellamy, *Digital Telephony, Second Edition*, Wiley Interscience, New York, 1991.

R. Handel and M. Huber, *Integrated Broadband Networks - An Introduction to ATM-Based Networks*, Addison-Wesley Publishers, New York, 1991.

M. Nesenbergs and D. Smith, "Mean synchronization times for ATM cells: Derivations and computational background," NTIA Report 91-273, March 1991.

W. Stallings, *ISDN and Broadband ISDN, Second Edition*, Macmillan Publishing, New York, 1992.

In addition to books on the subject, many trade publications are dedicating significant portions of their content to the topic of B-ISDN. Some specific magazine issues with significant content dedicated to B-ISDN follows. (This is not intended to be an exhaustive list, only to provide the reader with a starting point for individual research.)

Data Communication Magazine, Volume 24, Number 13, September 21, 1995.
Communications News Magazine, Volume 32, Number 9, September 1995.
IEEE Communications Magazine, Volume 34, Number 8, August 1996.
IEEE Communications Magazine, Volume 33, Number 9, September 1995.
IEEE Communications Magazine, Volume 33, Number 8, August 1995.
IEEE Communications Magazine, Volume 32, Number 8, August 1994.
IEEE Communications Magazine, Volume 32, Number 4, April 1994.
IEEE Communications Magazine, Volume 31, Number 9, September 1993.
IEEE Communications Magazine, Volume 31, Number 2, February 1993.
IEEE Networks Magazine, Volume 9, Number 5, September/October 1995.
IEEE Networks Magazine, Volume 9, Number 2, March/April 1995.
IEEE Networks Magazine, Volume 8, Number 6, November/December 1994.
IEEE Networks Magazine, Volume 7, Number 2, March/April 1993.
IEEE Networks Magazine, Volume 6, Number 5, September/October 1992.

Following are the I series of B-ISDN related Recommendations approved or in the approval process as reported by the Circular Letters of the ITU. It is current through Circular Letter 202 dated 8 February 1996. Any Recommendation more than two years old may be subject to revision at any time. Therefore, it is important to check with the ITU to obtain the latest version of any Recommendation.

- I.113 Vocabulary of Terms for Broadband Aspects of ISDN, 1993
- I.121 Broadband Aspects of ISDN, 1991
- I.150 B-ISDN Asynchronous Transfer Mode Functional Characteristics, 1995

- I.211 B-ISDN Service Aspects, 1993
- I.311² B-ISDN General Network Aspects, 1993
- I.321 B-ISDN Protocol Reference Model and its Application, 1991
- I.326 Functional Architecture of Transport Networks Based on ATM, 1995
- I.327 B-ISDN Functional Architecture, 1991
- I.353²
- I.356 B-ISDN ATM Layer Cell Transfer Performance, 1993
- I.361 B-ISDN ATM Layer Specification, 1995
- I.362 B-ISDN ATM Adaptation Layer (Aal) Functional Description, 1993
- I.363 B-ISDN ATM Adaptation Layer (Aal) Specification, 1993
- I.364 Support of Broadband Connectionless Data Services on B-ISDN, 1995
- I.371²
- I.413 B-ISDN User-Network Interface, 1993
- I.414 Overview of Recommendations on Layer 1 for ISDN and B-ISDN Customer Access, 1993
- I.432 B-ISDN User-Network Interface - Physical Layer Specification, 1993
- ¹I.580 General Arrangements for Interworking Between B-ISDN and 64 Kbit/s Based ISDN, 1995
- I.610 Operation and Maintenance Principles of B-ISDN Access, 1995
- I.731³ Types and General Characteristics of ATM Equipment, 1995
- I.732³ Functional Characteristics of Atm Equipment, 1995
- I.751³ Asynchronous Transfer Mode (ATM) Management of the Network Element View, 1995

B.6 Numbers of Interest IN B-ISDN

When conducting experiments in a B-ISDN environment, there are several values that are used for calculations on a regular basis. Following is a list of values that we found particularly useful in our work.

Aggregate Data Rate of STM-1/STS-3c	155.520 Mbit/s
Overhead Rate for STM-1/STS-3c	5.760 Mbit/s
ATM Rate for STM-1/STS-3c	149.760 Mbit/s

²Scheduled to be recommended for approval at the ITU-T Study Group 13 meeting April 29 - May 10, 1996.

³Recommended for approval at the ITU-T Study Group 15 meeting (November 13-24, 1995). Currently in the balloting process.

ATM Overhead Rate for STM-1/STS-3c	14.128 Mbit/s
ATM Payload Data Rate for STM-1/STS-3c	135.632 Mbit/s
Number of ATM Cells per STM-1/STS-3c Frame	44.1509 Cells
Number of ATM Cells per Second at STM-1/STS-3c	353208 Cells/s
DS-1 Data Rate	1.536 Mbit/s
DS-1 Aggregate rate when ATM encapsulated (Assume full cells with AAL 1)	1.732 Mbit/s
DS-3 Data Rate	44.736 Mbit/s
DS-3 Aggregate rate when ATM encapsulated (Assume full cells with AAL 1)	50.447 Mbit/s